3 December 1968

Materiel Test Procedure 10-2-198
General Equipment Test Activity

U. S. ARMY TEST AND EVALUATION COMMAND
COMMODITY ENGINEERING TEST PROCEDURE

LASER SAFETY GOGGLES

1. OBJECTIVE

The objective of this document is to prescribe the general test procedures to be used to determine the degree to which laser safety goggles meet the military requirements for technical performance and safety characteristics as described in the Qualitative Materiel Requirements (WMR's), Small Development Requirements (SDR's), and Technical Characteristics (TC's).

2. BACKGROUND

A requirement exists for a device to protect the vision of personnel involved in the operation of lasers. Lasers are devices which generate coherent electromagnetic radiation in a narrow beam of extremely high intensity. (See Glossary for definition of terms) Many lasers operate in the visible region i.e., the region of the spectrum to which the eye is most sensitive, and as such represent a hazard because of the eye's ability to focus the light on the retina and damage it. It is the function of the goggles to lower, by several optical techniques, the intensity to a point where it may be considered safe The goggles should be capable of protecting the eyes of the wearer from the primary beam and all resulting specular and diffuse reflections. Some of this energy may be in the ultraviolet or infrared areas of the spectrum and would not be visible. Ultraviolet radiation in particular can damage the cornea of the eye. Goggles are provided primarily for accidental viewing. The laser installation should be designed to avoid exposure and wherever possible personnel should not look directly at the laser beam. This is especially true with the high energy pulsed lasers. A high level of ambient light at the installation is also recommended to supplement the use of goggles.

3. REQUIRED EQUIPMENT

a. Trace Recording Spectrophotometer capable of generating radiation in the visible, infrared and ultraviolet regions.
b. Gas-filled Tungsten Filament Lamp color temperature 2854 deg. K.
c. Radiometer or Thermopile.
d. Optical Filter - deep red.
e. Hazemeter N.B.S. type or equivalent.
f. Telescope - 8 power used with 0.75 inch aperture and crosshairs in the focal plane of the ocular.
g. Resolving Power Chart 20 of N.B.S. publication M166 and N.B.S. circular C533.
h. Test Chart with central dot and (1) inch diameter concentric circle.
i. Two Standard Lenses - (1) plus 1/16 diopter, (1) minus 1/16 diopter.
j. Goggle Holding Stands.
k. Steel Ball - 7/8 inch diameter, 1.56 ounces.
l. Air Gun - 22 caliber with pellets.
m. Operating Laser.

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n. N.B.S. Tables on the spectral radiant energy of the C.I.E. source A and the relative luminous efficiency of the human eye.
o. Neutral Density Filters optical density values 0-50 O.D.

4. REFERENCES

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V. MTP 10-2-500, Physical Characteristics.
W. MTP 10-2-501, Operator Training and Familiarization.
X. MTP 10-2-505, Human Factors Evaluation.

5. SCOPE

5.1 SUMMARY

This MTP describes the following tests to be conducted in the evaluation of laser safety goggles:

a. Preparation for Test - A determination of the test item, its suitability for making further tests and operator training and familiarization.

b. Physical Characteristics - A determination of the physical characteristics of the test item.

c. Critical Wavelength Attenuation - An evaluation to determine the ability of the goggles to provide maximum attenuation at the wavelength of the expected laser usage.

d. Visible Light Transmission - An evaluation of the visible light transmitted by the goggles.

e. Infrared Transmittance - An evaluation of the infrared radiation light transmitted by the goggles.

f. Ultraviolet Transmission - An evaluation of the ultraviolet radiation transmitted by the goggles.

g. Haze Test - A study to determine the fraction of the total transmitted light from a normally incident beam which is not transmitted in a straight line. This test measures the light scattering properties of the goggles.

h. Definition - An evaluation to determine the ability of the goggles to provide angular resolution of closely spread targets.

i. Prismatic Power - An evaluation to determine the apparent displacement of objects due to undesirable prism like properties of the goggles.

j. Refractive Power - An evaluation to determine the degree of normal refraction in the goggles by comparison with two standards of known refraction.

k. Fracture Resistance - An evaluation to determine the physical strength of the goggle lenses in resisting the impact of an object with a specified momentum.

l. Breakage Pattern - An evaluation to determine the quality of the lens due to heat treatment by causing the lens to shatter under impact and observing the breakage pattern (A destructive test).

m. Primary Beam Exposure - An evaluation to determine the reaction of the goggles under the limiting condition of exposing them to the laser's primary beam. (A destructive test since permanent deformation or lens shattering may occur).

n. Safety - An evaluation of the safety characteristics of the test item.

o. Value Analysis - An evaluation to determine whether the test item has unnecessary, or costly features which can be eliminated without affecting the performance of the test item.

5.2 LIMITATIONS

None

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 Initial Inspection

The test item shall be subject to the following upon its arrival at the test site:

6.1.1.1 Packaging Inspection

Visually inspect the test item container and record the following:

a. Evidence of packing damage or deterioration.
b. Identification markings, including:

1) Name of contractor
2) Number and date of contract
3) Date of manufacture
4) All other pertinent markings

6.1.1.2 Test Item Inspection

Remove the test item from the container, visually inspect it and record the following, when applicable:

a. Evidence of defects:

1) Manufacturing
2) Material
3) Workmanship

b. Evidence of damage.
c. Evidence of wear.
d. Correlation of accompanying printed material data with the test item markings.

NOTE: The optical density at maximum wave length should be marked on each goggle.

6.1.2 Operator Training and Familiarization

Test personnel shall undergo the familiarization outlined in MTP 10-2-501 and the following:

a. Instruct all test personnel in the operation and safety of the laser safety goggles and associated equipment. Issue copies of the technical manuals and safety instructions. The purpose and method of testing will be presented.

b. User personnel shall be required to perform all operational functions of the test items under supervision of the test officer for a pre-determined period of time. Test personnel will be observed and their performance recorded on a data sheet.

c. Record the following for test personnel:

1) MOS
2) Rank
3) Unit
4) Amount of experience
5) Previous training
6) Adequacy of technical manuals for training purposes

6.1.3 Physical Characteristics

Physical characteristics of the test item shall be determined by performing the applicable portions of MTP 10-2-500 and the following:

NOTE: Materials used in the manufacture of eye protectors should exhibit mechanical strength, and the lightness of weight.

a. Verify that the materials used in the test item are non-irritating to the skin when subject to prespiration by obtaining a manufacturer's statement certifying non-irritability or by inspecting personnel using the test items in a high temperature environment for indications of irritability.

b. Inspect the test item to ensure that all metals used are inherently corrosion resistant.

c. Determine the quality of the lenses by holding the goggles up to a source of visible light and examining the goggle plates for and record indications of the following:

1) Internal striae
2) Bubbles
3) Waves
4) Other defects which impair optical quality

6.2 TEST CONDUCT

NOTE: 1. The following safety precautions shall be observed during all phases of testing:

a. Do not look directly into a laser beam.
b. Do not place goggles directly in a laser beam except for the destructive test specified.
c. Ensure that all personnel are adequately shielded from hazardous electromagnetic radiation.
d. All procedures shall comply with the safety procedures outlined in Appendix B.

2. Observe normal safety precautions described for each piece of test equipment, e.g., spectrophotometer and operating laser.

6.2.1 Critical Wavelength(s) Attenuation Test

6.2.1.1 Preparation for Test

a. Set up a spectrophotometer whose range of wavelengths includes the wavelength of the expected laser usage.

NOTE: The range of optical density values runs from 0 to 5 O.D. (See Appendix A for a description of the O.D. unit). Most instruments are incapable of such sensitivities. To overcome this, use the maximum sensitivity of the instrument and set the spectrophotometer slits to open symmetrically at the critical wavelength.

b. Calibrate the instrument with matched neutral density filters in both the reference and measuring sections.

NOTE: 1. These filters should have optical density values approximating that of the goggles, particularly for wavelengths of light equal to the critical wavelength(s).
2. The calibration curve should range from 2000 angstoms to two (2) microns.

c. Replace the filter in the measuring side of the instrument with the goggle lens or an equivalent thickness of test material.

NOTE: The transmittance value should be less than 100% but greater than 0. If the transmittance through the goggle lens does not fall in this range, different filters must be used.

6.2.1.2 Test Conduct

a. Measure and record the transmittance value at the critical wavelength(s).
b. Record the characteristics of the neutral density filter used (attenuation at the critical wavelength(s)).

6.2.2 Visible Light Transmission Test

6.2.2.1 Preparation for Test

a. Set up a spectrophotometer whose range of wavelengths includes the visual portion (4000 - 7000 Angstroms) and whose source operates at a color temperature of of 2854°K corresponding to a C.I.E. Standard Source A.
b. Mount the goggles so that the lens is centrally located in the measuring path.

6.2.2.2 Test Conduct

Energize the spectrophotometer and obtain a trace of the transmittance of visible light versus wavelength.

6.2.3 Infrared Transmittance Test

6.2.3.1 Preparation for Test

a. Prepare a high powered gas-filled tungsten lamp operating at a color temperature of 2854°K correponding to C.I.E. Standard Source A, a physical radiometer, e.g., a thermopile for operation.
b. Position the equipment so that the light from the lamp passes through a deep red filter, which has a high and uniform transmittance throughout the infrared spectrum and which transmits less than 0.5% of the luminous radiation and illuminates the radiometer.
c. Calibrate the radiometer to a suitable reference point (the radiometer effectively integrates the infrared radiation over its spectral density curve).

6.2.3.2 Test Conduct

a. Record the radiometer reading without the goggles in place.

b. Insert the goggles between the source and the radiometer and record the radiometer reading.

6.2.4 <u>Ultraviolet Transmission Test</u>

6.2.4.1 Preparation for Test

a. Set up a spectrophotometer whose range of wavelengths include the wavelengths 300-500 mulli-micron (violet and ultraviolet).

b. Place the goggles so that their lens plate is centered in the reference path.

6.2.4.2 Test Conduct

Energize the spectrophotometer and obtain a trace of transmittance versus wavelength.

6.2.5 <u>Haze Test</u>

6.2.5.1 Preparation for Test

a. Set up a haze meter of the type used by the National Bureau of Standards Plastics Section and described in ASA Z2.1 - 1959, P43.

b. Adjust the meter for an initial reading of 100 on the haze meter.

6.2.5.2 Test Conduct

a. Place the goggles so that the lens is centered over the photocell aperture and record the meter reading.

NOTE: This value is the percentage of total light transmission (T).

b. Move the goggles so that the lens is now centered over the exit aperture of the haze meter cylindrical light shield and record the meter reading.

NOTE: This value is the percentage of parallel light transmission (T_R).

6.2.6 <u>Definition Test</u>

6.2.6.1 Preparation for Test

a. Set up an eight power telescope which has an effective aperture of 0.75 inch.

b. Mount a resolving power chart 20 (National Bureau of Standards Miscellaneous Publications M166 or National Bureau of Standards Circular C533) at a distance of 35 feet from the objective of the telescope.

c. Illuminate the chart.

d. Focus the telescope.

6.2.6.2 Test Conduct

a. Place the lens of the goggles to be tested in front of the telescope and re-focus the telescope.
b. Record the degree of resolution.

NOTE: The pattern marked 20 should be clearly resolved at the test distance.

6.2.7 Prismatic Power Test

6.2.7.1 Preparation for Test

a. Set up an eight power telescope, which has an effective aperture of 0.75 inch and is equipped with crosshairs in the focal plane of the ocular.
b. Mount a test chart, comprised of a central dot and a concentric circle one inch in diameter, at a distance of 35 feet from the telescope objective.
c. Illuminate the chart and focus the telescope.

6.2.7.2 Test Conduct

a. Align the telescope so that the intersection of the crosshairs falls on the image of the central dot.
b. Place the lens of the goggles under test in front of the objective lens of the telescope and observe and record the position of the intersection of the crosshairs with respect to the image of the circle.

NOTE: The intersection of the crosshairs will fall outside of the image of the circle if the prismatic power of the goggles exceeds 1/8 prism diopter.

6.2.8 Refractive Power Test

6.2.8.1 Preparation for Test

Repeat the procedures of paragraph 6.2.7.1.

6.2.8.2 Test Conduct

a. Calibrate the telescope by performing the following:

1) Place a plus 1/16 diopter lens in front of the telescope objective, focus the telescope and mark the position of best focus.

NOTE: The position of best focus can be referenced by light marks made on the drawtube.

2) Repeat step a.1 using a minus 1/16 diopter lens.

b. Place the goggle lens in front of the telescope objective and focus

the telescope.

c. Observe and record the position of best focus when the goggle lens is in place (If this position is not within the calibration marks of step a, record whether the excess is plus or minus).

6.2.9 Fracture Resistance Test

a. Mount the goggles in a stand which will firmly support the frame but not touch the lenses.

NOTE: The lenses will be mounted in a horizontal plane facing upwards.

b. Raise a steel ball of 7/8 inch diameter and approximately 1.56 ounces in weight to a height of 50 inches above the center of the lens and allow it to drop freely striking the horizontal upper surface of the lens.

c. Observe and record evidence of the following:

1) Chipping of edge of lens
2) Cracking or shattering of lens
3) Displacement of lens from frame

6.2.10 Breakage Pattern Test

6.2.10.1 Preparation for Test

a. Mount the goggles in a holder which will firmly support the frame but not touch the goggle lenses.

NOTE: The lenses will be in a vertical plane toward the observer.

b. Prepare a 22 caliber air gun with pellets for operation.

NOTE: The gun should have a pressure velocity calibration curve.

6.2.10.2 Test Conduct

a. At a suitable range so as to have the pellet strike the center of the lens, fire a pellet having a velocity of 65 feet/sec. at the goggle lens.

b. Repeat step a, increasing the pellet velocity by 5 feet/sec. each round until the lens shatters.

c. Record pellet velocity at which shattering occurs.

NOTE: The lens shall break predominately with radial cracks with a minor tendency towards concentric cracks. If the shattering causes lines of cleavage parallel to the surface, the heat treatment will be considered unsatisfactory.

6.2.11 Primary Beam Exposure Test

6.2.11.1 Preparation for Test

a. Prepare a laser, which operates at the wavelength for which the goggles provide the greatest attenuation, for operation.

b. Mount the goggles in a holder with the lenses vertical such that the lens surface area is approximately 100% visible both front and rear.

c. Move the holder into the laser beams previously determined location so that the lens will interrupt the beam path.

6.2.11.2 Test Conduct

a. Operate the laser at the minimum level and minimum length of time specified in the test plan.

NOTE: For a continuous wave laser, allow several seconds and for a pulsed laser, allow several pulses.

b. Examine the lens visually and under a microscope, record indications of the following:

1) Heating
2) Deformation
3) Breakage
4) Hair cracks

c. Repeat the procedures of paragraphs a and b, increasing the energy densities until it is determined at what levels the protective qualitites of the goggles are defeated.

6.2.12 Safety

NOTE: The optical density at maximum wavelength is to be marked on each goggle.

Determine the safety characteristics of the test item as follows:

a. The overall safety characteristics of the test item shall be determined by analyzing the results of all subtests and a safety release shall be issued in accordance with USATECOM Regulation 385-6.

b. Throughout the test, observe and record any condition, that might constitute a safety hazard, the cause of the hazard and steps taken to alleviate the hazard.

c. Record any deficiencies in safety markings or instructions and make appropriate comments for improvement.

6.2.13 Human Factors Evaluation

The goggles shall be subjected to the applicable portions of MTP 10-3-5-5 and the following:

a. Head fit - The goggles when put on shall fit comfortably on the head, shall be adjustable to allow fit and shall have no rough edges which can cause discomfort. Record the degree of comfort.

b. Peripheral leakage - With the goggles on the user in an environment of high ambient light intensity, no light shall be visible from the inner periphery of the goggles. Record the position of leakage on the periphery and the degree of leakage, if any.

c. Field of vision - The goggles shall allow an effective angle of vision of not less than 105 degrees assuming that the pupil of the eye is located approximately 17 millimeters behind the inner surface of the goggle plates. Record the approximate angle of vision.

d. Ventilation - The goggles shall be vented in such a manner so as to prevent fogging by allowing circulation of air but baffled to prevent passage of light. Record performance of this feature.

6.2.14 Value Analysis

Perform the following:

a. When using the laser safety goggles observations will be made to determine whether the goggles incorporate any features that could be eliminated without compromising their performance, reliability, durability or safety.

b. During the conduct of the test, the users will be informally questioned regarding any features of the goggles that may be eliminated without decreasing their functional value. All user comments regarding value analysis will be recorded in the daily log.

c. The test team members will study the goggles during use and will comment separately in the daily log on elimination of unnecessary features, using their experience and background with respect to value analysis.

6.3 TEST DATA

6.3.1 Preparation for Test

6.3.1.1 Initial Inspection

6.3.1.1.1 Packaging Inspection -

Record the following:

a. Evidence of package damage or deterioration
b. Identification markings:

1) Name of contractor
2) Number and date of contract
3) Date of manufacture
4) Other pertinent markings

6.3.1.1.2 Test Item Inspection -

a. Record the following:

1) Manufacturing
2) Material

3) Workmanship

b. Evidence of damage.
c. Evidence of wear.
d. Evidence of defects.
e. Presence of identification markings and agreement with accompanying data sheets.
f. Optical density at maximum wavelength.

6.3.1.2 Operator Training and Familiarization

Record the following:

a. MOS
b. Rank
c. Unit
d. Amount of experience
e. Previous training
f. Adequacy of technical manuals for training purposes

6.3.1.3 Physical Characteristics

Record data collected as described in the applicable sections of MTP 10-2-500 and the following, as applicable:

a. Degree of skin irritation caused by materials used in goggles.
b. Presence of corrosive materials in goggles.
c. Presence of the following defects in lens:

1) Internal striae
2) Bubbles
3) Waves
4) Other defects which impair optical quality

6.3.2 <u>Test Conduct</u>

6.3.2.1 Critical Wavelength Attenuation Test

Record the following for each critical wavelength:

a. Critical wavelength(s)
b. The spectrophotometer readings
c. Attenuation of the neutral density filter at the critical wavelength(s)

6.3.2.2 Visible Light Transmission Test

Retain the trace of visible light transmittance versus wavelength of the test item.

6.3.2.3 Infrared Transmittance Test

Record the following:

a. The radiometer reference reading (without the goggles in the test setup).
b. The radiometer reading with the goggles inserted.

6.3.2.4 Ultraviolet Transmittance Test

Retain the trace of the transmittance versus wavelength.

6.3.2.5 Haze Test

Record the following:

a. Haze meter reading with the lens centered over the photocell aperture (T).
b. Haze meter reading with the lens at the exit aperture of the light shield (T_R).

6.3.2.6 Definition Test

Record the relative degree of resolution of the power chart with the goggles in front of the telescope (pattern number).

6.3.2.7 Prismatic Power Test

Record position of telescope crosshair with respect to test chart circle (inside or outside).

6.3.2.8 Refractive Power Test

Record position of best focus with the goggle lens in front of the telescope objective (within the calibration marks, greater than 1/16 diopter, or less than 1/16 diopter).

6.3.2.9 Fractive Resistance Test

Record evidence of the following:

a. Chipping of lens edge
b. Cracking or shattering of lens
c. Displacement of lens from frame

6.3.2.10 Breakup Pattern Test

Record the following:

a. Pellet velocity at which breaking occurs in feet/sec.
b. Class of breakage:

1) Type breakage lines (radial or concentric circle)

2) Number of each type of breakage line

6.3.2.11 Primary Beam Exposure Test

Record the following:

a. Wavelength(s) of laser beam
b. For each exposure to the laser beam:

1) Energy density test item is subjected to
2) Exposure time, in seconds
3) Effects of laser:

a) Heating
b) Deformation
c) Breakage
d) Hair cracks

6.3.2.12 Safety

Record the following:

a. Normal safety precautions followed in the test procedures.
b. Any condition that might present a safety hazard, cause of hazard, and steps taken to alleviate the hazard.
c. Deficiencies in safety markings or instructions and comments for improvement.

6.3.2.13 Human Factors Evaluation

Record data collected as described in the applicable sections of MTP 10-2-505 and the following:

a. Fit and degree of comfort which the user has when wearing the goggles.
b. For peripheral leakage, if any:

1) Position of leakage in the periphery
2) Degree of leakage

c. Approximately effective angle of vision, in degrees
d. For adequacy of ventilation:

1) Evidence of lens fogging, if any.
2) Presence of excessive rise in temperature level at the skin area covered by the goggles.
3) Degree of light leakage through vents, if any.

6.3.2.14 Value Analysis

Record the following:

Comments of test team personnel and users on features of the test item

that could be eliminated without compromising their performance, reliability, durability, or safety.

6.4 DATA REDUCTION AND PRESENTATION

6.4.1 Critical Wavelength Attenuation Test

The optical density for the goggles will be the sum of the optical density value for the neutral density filter used and the optical density difference between the filter and the goggles calculated from the spectrophotometer reading (R):

$$\text{Optical density} = \log_{10} \frac{I_0}{I} \quad \text{where now } I = RI_0$$

$$= \log_{10} \frac{1}{R}$$

Compare the measured value for optical density against the test item specification and the manufacturers quoted value.

6.4.2 Visible Light Transmission Test

Using the table which gives the relative luminous efficiency of the average eye, correct each of the readings obtained from the spectrophotometer. Sum the newly derived readings to obtain the total visual transmission. Compare this figure against the test item specification and the manufacturers quoted value by plotting each set of values.

6.4.3 Infrared Transmittance Test

Using the radiometer reference reading (L_1) and the radiometer reading with the goggles in the test setup (L_2), calculate the percentage of the infrared transmittance.

$$\text{Percentage of infrared transmittance} = \frac{L_2}{L_1} \text{ X } 100$$

Compare the calculated value for the infrared transmittance against the test item specification and the manufacturers quoted value.

6.4.4 Ultraviolet Transmission Test

Using the transmission chart from the spectrophotometer and the recorded values for the wavelengths of the light source used, verify the test item's specifications and the manufacturer's quoted values for ultraviolet transmittance. Present the results graphically.

6.4.5 Haze Test

Using the figures for the total light transmitted (T) and the parallel light transmitted (T_R) calculated the haze figure.

$$\text{Haze} = \frac{t \quad T - T}{T}$$

Where applicable this figure will be compared with quoted values for the goggles.

6.4.6 Other Test Data

The remaining data will be summarized using charts and graphs, as applicable. All data will be analyzed to determine compliance with the QMR's, SDR's and military specifications for the test item or as described in the applicable section of the appropriate MTP.

GLOSSARY

1. Angstrom (A°): Unit of measure of wavelengths equal to 10^{-10} meter or 0.1 nanometer (millimicrons).
2. Beam Divergence: Angle of beam spread in milliradians (1 milliradian = 3.4 minutes of arc).
3. Closed Installation: Any location where lasers are used which will be closed to personnel during laser operation such as remote firing and TV monitored operations.
4. C. W. Laser: Continuous wave laser as distinguished from a pulsed laser.
5. Decibel (db): The unit used to express a beam intensity ratio. The decibel is equal to 10 times the logarithm of the beam intensity ratio as expressed by the following equation:

$$n(db) = 10 \log_{10} \frac{(P_1)}{(P_2)}$$

Where P_1 and P_2 designate two amounts of power or energy density and n the number of decibels corresponding to their ratio.

6. Electromagnetic Radiation: The propagation of varying electric and magnetic fields through space at the speed of light.
7. Emergent Beam Diameter: Diameter of the laser beam at the exit aperture of the system.
8. Energy Density: The intensity of electromagnetic radiation per unit area per pulse expressed as joules per square centimeter.
9. Gas Laser: A class of laser in which the laser action takes place in a gas medium usually a C. W. Laser.
10. Hazard Evaluation Survey: Evaluation of the hazards to personnel working or remaining in the vicinity of laser equipment.
11. Joule (j): A unit of energy. Used in describing a single pulsed output of a laser. It is equal to one watt-second or 0.239 gram-calories.
12. Joule/cm² (j/cm²): Unit of energy density used in measuring the amount of energy per area of absorbing surface or per area of a laser beam. It is a unit for predicting damage potential of a laser beam.
13. Laser: Light amplification by stimulated emission of radiation.
14. Laser Light Region: A portion of the electromagnetic spectrum which includes ultraviolet, visible, and infrared light.
15. Maser: Microwave amplification by stimulated emission of radiation. When used in the term optical maser, it is often interpreted as molecular amplification by stimulated emission of radiation.
16. Maximum Permissible Power or Energy Density: The intensity of laser radiation that, in light of present medical knowledge, is not expected to cause detectable bodily injury to a person at any time during his lifetime.
17. Open Installation: Any location where lasers are used which will be open during laser operation to operating personnel and may or may not specifically restrict entry to causuals.
18. Optical Density (OD): A logarithmic expression of the attenuation afforded by a filter. Alternatively, OD may be expressed as one-tenth the attenuation in db.
19. Optically Pumped Laser: A class of laser which derives its energy from a

noncoherent light source such as a xenon flash lamp. This laser is usually pulsed.

20. Output Power and Output Energy: Power is used primarily to rate C. W. lasers since the energy delivered per unit time remains relatively constant (output measured in watts). However, pulsed lasers which have a peak power significantly greater than their average power produce effects which may best be categorized by energy output per pulse. The output power of C. W. lasers is usually expressed in milliwatt (mw = 1/1000 watts), pulsed lasers in kilowatts (1000 watts), and q-switched pulsed lasers in megawatts (MW = million watts) or gigawatts (GW = billion watts). Pulsed energy output is usually expressed in joules.
21. Power Density: The intensity of electromagnetic radiation present at a given point. Power density is the average power per unit area usually expressed as milliwatts per square centimeter.
22. Pulsed Laser: A class of laser characterized by operation in a pulsed mode, i.e., emission occurs in one or more flashes of short duration (pulse length).
23. Pulse Length: Duration of laser flash. May be measured in milliseconds (msec = 10^{-3} sec), microseconds (μ sec = 10^{-6} sec), or nanoseconds (nsec = 10^{-9} sec).
24. Q-Switched Laser: (Also known as Q-spoiled) A pulsed laser, capable of extremely high peak powers, for very short durations (pulse length of several nanoseconds).
25. Semiconductor or Junction Laser: A class of laser which normally produces relatively low power outputs. This class of laser may be "tuned" in wavelength and has the greatest efficiency.
26. Solid-State Laser: A class of laser which utilizes a solid crystal such as ruby or glass. This class most commonly is used as an optically pumped, pulsed laser.
27. Metric and Exponential Systems: The following explanation of the metric system and the the exponential method of expressing numbers is presented as a source of reference:

(1) Metric System Abbreviations:

meter - m
centimeter - cm
millimeter - mm
micron - μ
nanometer - nm
angstrom - Å

Equivalent Units

1 m = 100 cm = 1,000 cm = 39.37 inches
1 cm = 0.3937 inches; 1 inch = 2.54 cm
1 μ = 10^{-6} meters = 10^{-4} cm
1 msec = 1/1,000 seconds = 1 x 10^{-3} seconds
1 μ sec = 1/1,000,000 seconds = 1 x 10^{-6} seconds
1 nsec = 1 x 10^{-9} seconds
1 milliradian = 10^{-3} radians = .057 degrees = 3.4 arc-minutes

(2) Exponential System: For convenience in writing and manipulation, unwieldy numbers are written as factors of appropriate powers of .10. The following examples will illustrate:

$2{,}380{,}000{,}000 = 2.38 \times 10^{9}$
$238 = 2.38 \times 10^{2}$
$0.238 = 2.38 \times 10^{-1}$
$0.000000238 = 2.38 \times 10^{-7}$

APPENDIX A

LASER SAFETY GOGGLE CHARACTERISTICS

Laser safety goggles are available in two basically different constructions and provide attenuation of the incident radiation by either or both of the optical phenomena of reflection and absorption. One type of goggles uses a dichroic outer glass plate and a colored filter backup plate. With this arrangement, approximately 98% of the incident radiation is reflected while the remainder is reduced to heat by absorption at the colored filter. The second type of goggles uses two absorption filters with the outer filter being the one of lower absorption coefficient. This construction obviously provides attenuation through multiple absorption. Both constructions have an additional common safety factor: backup protection in the event of fracture or destruction of the outer plate.

Goggles are wavelength specific, i.e., maximum attenuation is provided at one wavelength, and should be selected on the basis of the particular laser in use and the intensity reduction required. The most important characteristic of the goggles is their efficiency as an attenuator. This efficiency is ascertained by measuring the transmittance which is the ratio of the intensity of the radiation at the exit side (1) to the intensity at the entrance side (I_o). This technique accounts for both reflection and absorption. The measure of efficiency is given by the optical density defined by equation (1).

$$\text{Optical Density} = \text{LOG}_{10} \frac{1}{\text{Transmittance}} = \text{LOG}_{10} \frac{I_o}{I} \qquad \text{EQ (1)}$$

Figure A-1 is a typical plot of optical density versus wavelength and Table A-1 lists representative values found with goggles used with particular lasers.

In determining the true safety value of goggles, a comparison should be made of the goggle exit intensity to that intensity which is considered safe at the eye. However medical research in the field of determining safe values of exposure has not produced generally agreed upon safe levels.

TABLE A-I

REPRESENTATIVE VALUES FOR GOGGLE CHARACTERISTICS

GOGGLE NUMBER	Argon 4880 ANGSTROMS	HeNe 6328 ANGSTROMS	Ruby 6943 ANGSTROMS	GaAs 8400 ANGSTROMS	Nd 10600 ANGSTROMS	CO_2 10.6 MICRONS	UV PROJECTION	NO. OF FILTERS AND THICKNESS	VISIBLE LIGHT TRANSMISSION
1	0.2	2	3.5	4	2.7	0	Yes	1,3.5 mm	27.5%
2	0.6	4.1	6.1	5.5	3	0	Yes	1,3.5 mm	9.6%
3	0	1	5.0	13.5	10.9	735	Yes	2,2 mm	46%
4	0.3	2	8.0	21.0	17.1	735	Yes	2,2 mm	35%
5	13.5	0	0	0	0	735	Yes	1,3 mm	23.7%
6	11.4	0	0	0	0	735	Yes	1,2.5 mm	24.7%
7	0	0	0	0	0	50	No	1,2,75mm	100%
8	15	0.2	0	0	0	35	Yes	1,7.9 mm	4.3%
9	4	0	0	0	0.1	35	Yes	1,7.9 mm	57%
10	0.8	12.2	15.5	5.6	4.8	35	Yes	1,6.4 mm	6.2%
11	0.9	4.5	7.7	11.8	5.7	35	Yes	1,7.1 mm	8.0%
12	1.9	1.8	2.2	4.8	7.5	35	Yes	1,7.6 mm	3.0%
13	2.7	6.0	10	10	10	0	No	1,6 mm	50%
14	5	5	9	18	13	3	Yes	3,6.3 mm	25%

OPTICAL DENSITY VALUES

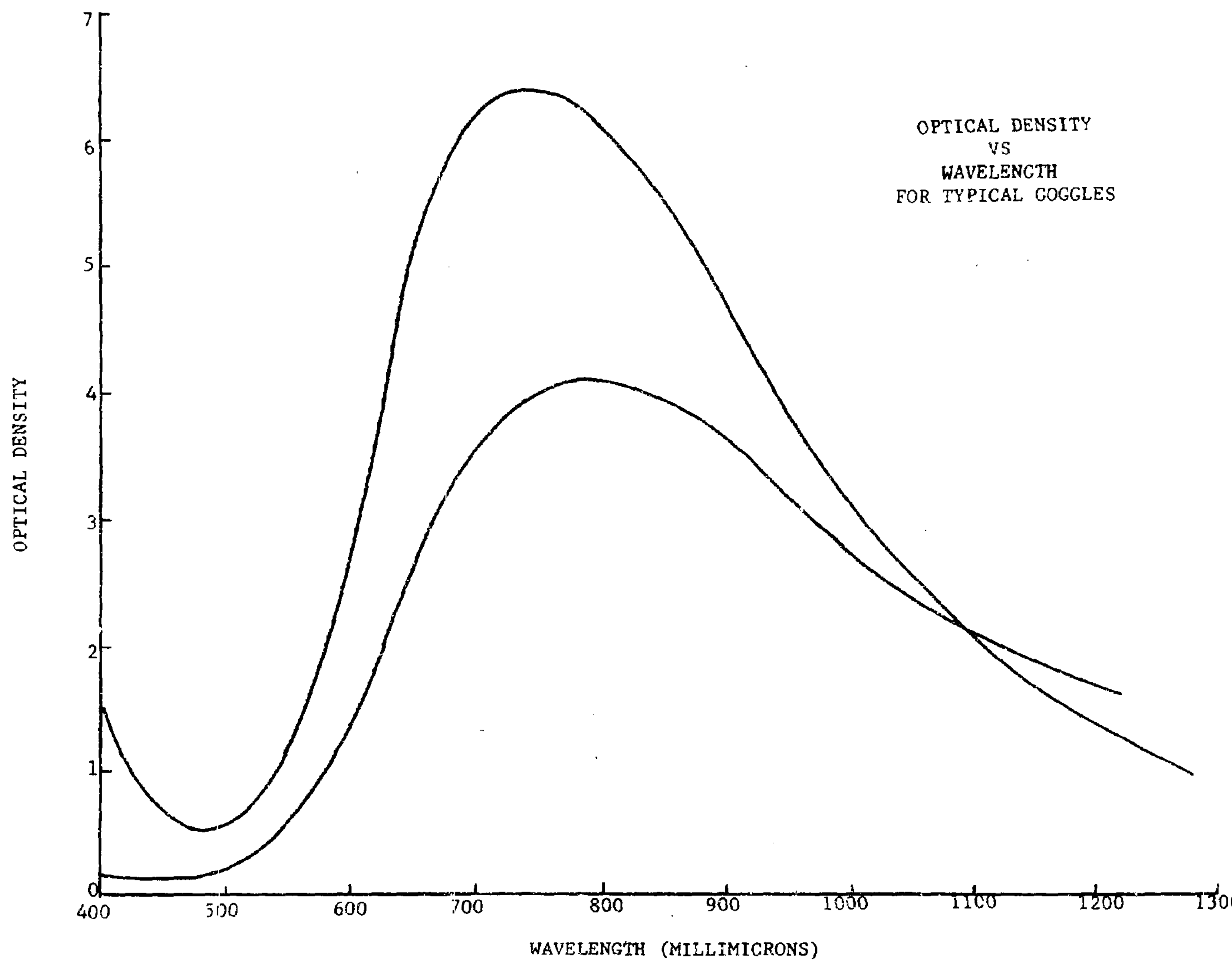

OPTICAL DENSITY
VS
WAVELENGTH
FOR TYPICAL GOGGLES
OPTICAL DENSITY
0
1
2
3
4
5
6
7
400
500
600
700
800
900
1000
1100
1200
1300
WAVELENGTH (MILLIMICRONS)

Figure A-1

APPENDIX B

CONTROL OF HAZARDS TO HEALTH FROM LASER RADIATION

1. INTRODUCTION

Recent developments in laser technology have resulted in an increase in the utilization of these devices for military applications, both for research and field use. Moreover, the widespread use of these systems greatly increases the probability of personnel exposure to injurious intensities of laser radiation. Therefore, it is highly important that adequate protective measures be employed to prevent accidental injury. This publication has been prepared in the interest of expediting implementation of such measures.

2. CHARACTERISTICS OF LASER RADIATION

Existing laser systems utilize portions of the electromagnetic spectrum including ultraviolet, visible and infrared light. This wavelength increment is commonly designated as the "light" region of the electromagnetic spectrum. The following characteristics of this type of radiation become apparent when it is inserted into its proper position in the electromagnetic spectrum, and its location noted in relation to the circumscribing wavelengths:

a. It is bounded on the short wavelength end of the electromagnetic spectrum by far ultraviolet. It should not be confused with ionizing radiation (x and gamma rays) although very high power or energy densities have been known to produce ionization in air and other material.

b. It is bounded on the long wavelength end of the electromagnetic spectrum by far infrared.

c. The effects of laser radiation are essentially the same as light generated by more conventional ultraviolet (u.v.), infrared (i.r.) and visible light sources. The unique properties attributed to laser radiation are generally those resulting from the very high intensities and high monochromaticity of laser light. Laser light sources differ from conventional light emitters primarily in their ability to attain highly coherent light (in phase). The increased directionality and intensity of the light generated by a laser enables it to deliver concentrated light intensitites at considerable distances (miles). Although these effects can be used to good advantage, they are potentially dangerous and must be given careful consideration.

3. BIOLOGICAL EFFECTS OF LASER RADIATION

a. The biological effects of the laser beam are essentially those of visible, ultraviolet or infrared energy upon tissues. However, the intensity of the light is of magnitudes that could previously be approached only by the sun, nuclear weapons, magnesium burning or arc lights. This is one of the important properties that make lasers exceedingly hazardous.

b. A laser beam striking tissue will be reflected, transmitted, and/or absorbed. The degree to which these occur depends upon various properties of the tissue involved. Absorption is selective, as in the case of visible light, darker material such as melanin or other pigmented tissue absorbing the energy.

c. Skin effects may vary from mild reddening or erythema, to blisters and charring, depending upon the amount of energy transferred. Dark skin is more sensitive than light skin.

d. The effect upon the retina may be physiological i.e., a temporary spot without pathologic changes, or it may be more severe with pathologic changes that heal by fibrosis. The least reaction may be simple reddening; as the energy increases, the lesions progress in severity from blistering to edema, ulceration, and charring, with tissue reaction around the lesion. Very high energies will disrupt the retina and the eye. Portions of the eye, superficial to the retina, may also be injured, depending upon the region where the greatest absorption occurs and the relative sensitivity of tissue affected. (See Figures 8-1 and 8-2 for Eye Radiation Absorption Properties and Wavelength Effect on the Ocular Media).

e. Infrared light produces heat with its characteristic effect on tissue and the lens of the eye. Ultraviolet light produces "flash burn", an acute inflammation of the conjunctiva, common in arc welders. Light in the far infrared such as the 10 micron wavelength from the carbon dioxide lasers may be absorbed only in the cornea.

f. The following table indicates the minimum retinal exposure level that will produce retinal damage which can be observed ophthalmoscopically for three types of lasers.

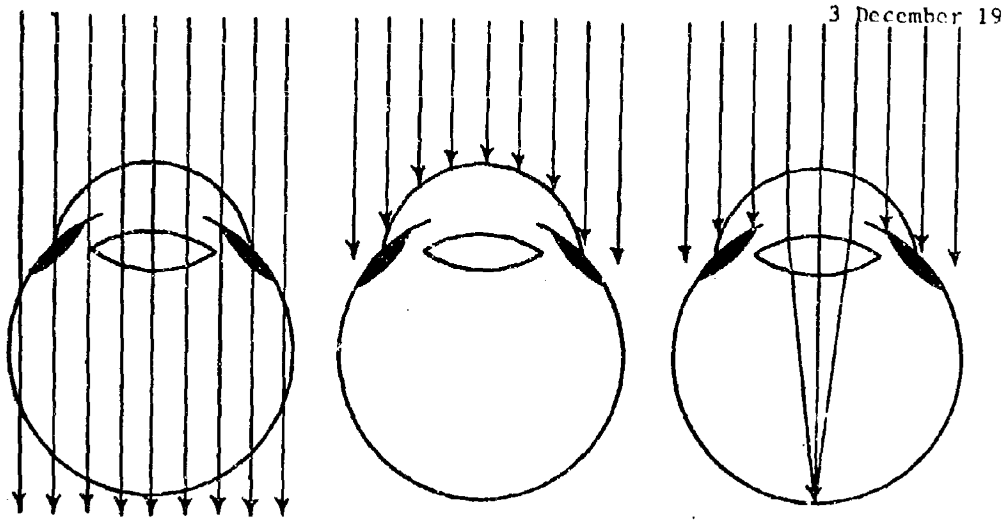
TABLE B-I

TYPE	WAVELENGTH	PULSE DURATION	LEVEL
Non-q-switched	6943Å	200 microsec.	0.85 joules/cm^2
Q-switched	6943Å	30 nanosec.	0.07 joules/cm^2
Continuous Wave	White Light	----------	6.0 watts/cm^2

It is reasonable to assume that the threshold levels for other wavelengths absorbed at the retina (specifically the pigment epithelium) are approximately the same. It is emphasized that, due to the focusing effect of the eye, the energy density at the retina will be several orders of magnitude greater than the level before entering the eye. There is evidence that unobservable retinal changes are produced by energy densities approximately fifty percent below those shown in the table (i.e., q-switched-0.035 j/cm^2, and non-q-switched at 0.43 j/cm^2).

4. MEDICAL SURVEILLANCE

An individual whose occupation or assignment may result in over-exposure to laser radiation should have a preplacement medical examination and a periodic eye examination, preferably, at six month intervals, or at such other times as there may be reason to believe that eye damage from laser may have occurred. A general eye examination, near and distance visual acuity and a detailed ophthalmoscopic evaluation of the retina should be made. A retinal fundus photograph of the foveal area at the time of preplacement examination is advisable. It is advisable to repeat this at anytime retinal damage is suspected. For individuals exposed to lasers emitting radiation in the ultraviolet and infrared regions, it is advisable to make a slit lamp examination periodically.



GAMMA AND X RADIATION

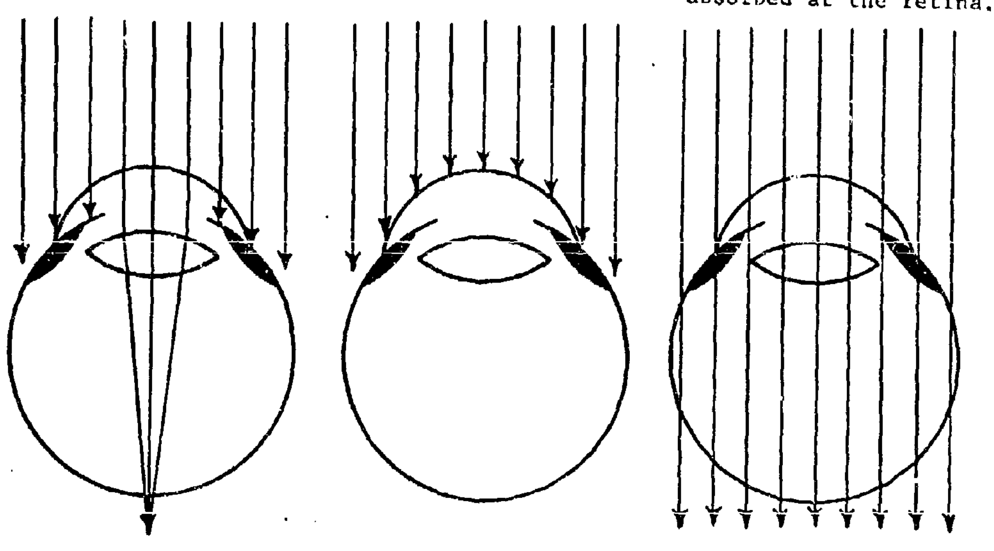
a) Most higher energy x-rays and gamma rays pass completely through the eye.

SHORT ULTRAVIOLET

b) Absorption occurs principally at the cornea.

LONG ULTRAVIOLET AND VISIBLE

c) Light is refracted at the cornea and lens and absorbed at the retina.



NEAR INFRARED

d) Energy is absorbed in the ocular media and at the retina; near infrared rays are refracted.

FAR INFRARED

e) Absorption is localized at the cornea.

MICROWAVES

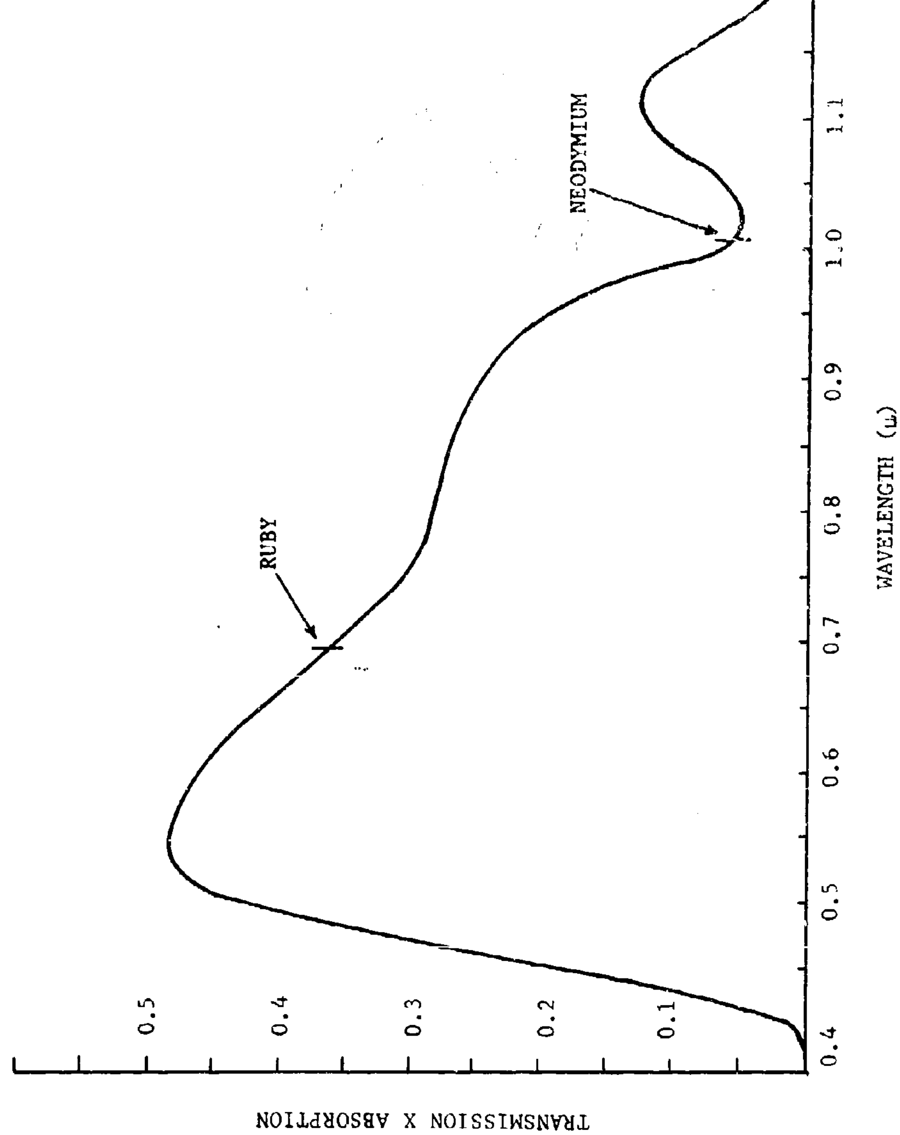
f) Microwave radiation is transmitted through the eye although a large percentage may be absorbed

Figure B-1 ABSORPTION PROPERTIES OF THE EYE FOR ELECTROMAGNETIC RADIATION

TRANSMISSION IN OCULAR MEDIA TIMES ABSORPTION IN PIGMENT EPITHELIUM

VS.

WAVELENGTH



5. EXPOSURE OF PERSONNEL

a. Eye Exposure

(1) Design Criteria. An energy density of 1×10^{-7} joules per square centimeter at the cornea is considered to be a practical criterion for design purposes in the development of q-switched laser devices. Since this energy level is believed to be close to "the damage threshold", it should not be used for purposes of hazards evaluation of devices in use.

(2) Occupational Exposure Levels. Maximum permissible exposure levels at the cornea depend on several factors including the wavelength of the radiation, duration of exposure and pupil size (dependent upon ambient light levels). Exposure of the eyes to direct illumination or specular (mirror-like) reflections should not exceed the levels in the following table

TABLE B-II

Maximum Permissible Occupation Exposure Levels for Laser Radiation at the Cornea for Direct Illumination or Specular Reflection at $\lambda = 6943\text{Å}$

	Daylight 3mm pupil	Laboratory 5mm pupil	Night 7.5mm pupil
Q-switched pulse Joules/cm^2	5×10^{-8}	2×10^{-8}	1×10^{-8}
Non-q-switched pulse Joules/cm^2	5×10^{-7}	2×10^{-7}	1×10^{-7}
Continuous Wave Laser Watts/cm^2	5×10^{-6}	2×1^{-6}	1×10^{-6}

These levels could be adjusted for other wavelengths by using the graph of energy transmitted to, and absorbed at, the retina (Figure B-2), and normalizing the curve at $\lambda = 6943\text{Å}$. However, under no circumstances should these adjusted levels exceed the corresponding levels in Table B-II by a factor greater than ten.

b. Skin Exposure

Maximum permissible exposure levels for the skin should not exceed the nighttime levels for the eye (Table B-II) by a factor or more than 10^5 (u.v. not applicable).

6. HAZARD EVALUATION

As the eye is the structure most sensitive to damage from a laser beam, hazard evaluation based on safe levels for this structure can safely be applied to the entire body.

a. Hazard Evaluation of the Primary Beam (direct viewing)

The worst possible situation would exist if the eye were focused at infinity and the beam concentrated at the retina in a diffraction spot. Under these conditions the levels in Table B-II, would be applicable. The beam intensity at the point of interest may be calculated by Equation (2) of paragraph 10.

b. Viewing the Reflected Beam

(1) Specular Reflection. Specular reflection requires a mirror-like surface. If the reflecting surface is flat, the characteristics of the reflected beam may be considered identical to those of the direct beam except that the range is the sum of the distances from the laser source to reflector and from reflector to the eye. If the surface is not flat, the reflected light intensity arriving at the retina is less and may be readily calculated for a uniformly curved surface, if the curvature is known.

(2) Diffuse Reflection. The reflection from a flat diffuse surface obeys Lambert's law (see Equation (4) of paragraph 10) which relates the energy or power per solid angle to the surface brightness (i.e., essentially the "inverse square law"). A maximum brightness for the illumination of a diffuse material may be calculated from Table B-III. Such a maximum brightness would be the same regardless of the distance of the viewer or apparent size of the image, since the energy or power density at the retina remains the same. If the size of the reflection subtends an angle less than θ_{min} (Equation (5), paragraph 10), the maximum allowable brightness may be greater. In this case, the level of reflected light arriving at the eye may again be calculated by Lambert's Law. The level reaching the retina may then be calculated in the same manner as for direct viewing.

TABLE B-III

Maximum Illuminance from a Diffuse Surface Reflection as Measured at the Reflecting Surface

Nature of Exposure	Environment		
	Daylight 3mm pupil	Laboratory 5 mm pupil	Night 7.5mm pupil
Q-switched Pulse Joules/cm^2	.45	.15	.07
Non-q-switched Pulse Joules/cm^2	5.5	2.0	.9
Continuous Wave Laser Watts/cm^2	13.5	6.0	2.5

NOTE: The actual illuminance from a diffuse surface may be calculated by multiplying the energy or power density of the beam impinging upon the surface by the reflectance (a property of the material).

c. Other Factors

(1) Atmospheric Effects. The effect of atmospheric attenuation may become a major factor in evaluating the energy or power density at distances greater than a few kilometers. This attenuation is the sum of three effects; first, Mie (or large particle) scattering, where the particle size is greater than λ (wavelength of the light), and is normally the greatest contributor; second, Rayleigh (or molecular) scattering (where particle size is much less than the wavelength) is reasonably constant for a given wavelength; and, third, absorption by gas molecules which is relatively insignificant in comparison to scattering and may, therefore, be disregarded. Attenuation due to scattering is much more pronounced at shorter wavelengths, thus red light from a ruby laser is scattered far less than wavelengths in the blue end of the visible spectrum. A clean atmosphere may, therefore, be expected to be quite transparent to the ruby wavelength. The atmospheric attenuation effect upon a non-diverging beam is expressed by Equation (1) of paragraph 10. The scattering effect may attenuate a ruby laser beam by as little as 10% at 10 kilometers and 60% at 100 kilometers. Atmospheric turbulence results in increased attenuation, but assuming a very stable atmosphere (the worst possible case), this effect can be disregarded. The meteorological visibility, based upon the entire visible spectrum, may not be readily utilized in arriving at the attenuation coefficient at a given wavelength.

(2) Effect of Optical Viewing Instrument

(a) Viewing Diffuse Reflection. The effect on the retinal energy density, by viewing a diffuse reflection of an extended object through a telescope, is often to lower it slightly. This is due to the fact that, although the total light energy entering the eye is greater, it is distributed over a greater area on the retina. The maximum increase in light energy entering the eye is the ratio of the area of objective aperture to the area of the exit pupil aperture. The true value will be slightly less due to the absorption of some light in the optical system. The size of the image is increased by the magnification (or power) of the optical system which results in an increase of image area of the power squared. The energy or power density of a retinal image does not vary for subject-to-reflection distance as long as the image is not diffraction-limited.

(b) Viewing Specular Reflection. If, however, the laser beam is viewed directly, or by specular reflection, the laser spot size is, essentially, a point source and is still diffraction-limited upon "magnification" by the optical system. The power, then, does not affect the energy density since the image size is still a retinal diffraction pattern, thus allowing the optical device to increase the retinal energy density considerably. The situation may be further complicated by an image not quite being diffraction-limited. For the purpose of simplification, it may be assumed that the level on the retina will increase as the square of the magnification of the optical instrument.

7. EXPOSURE CONTROL

Control of occupational hazards, incidental to the user of lasers, must be aimed at maintaining exposures not greater than the maximum permissible level. Potential occupational hazards include: damage to the eyes, skin and other human

organs; "burns" from contact with liquid nitrogen or other substances used as coolants; electrical shock; exposure to gases such as ozone; and explosions at capacitor banks, optical pump systems and target areas. A complete safety program must be maintained for the protection of operating personnel and other persons who may be required to be present at laser installations. Suitable control should be provided as indicated by the nature of the operation. Provision for a closed installation is desirable. The equivalent of a closed installation can be achieved by installing a laser in a light-proof enclosure. Where neither of these alternatives are followed, an open installation results and the following safeguards should apply:

a. General Precautions Applicable to All Laser Installations

(1) Looking into the primary beam and at specular reflections of the beam must be avoided when power or energy densities exceed the maximum permissible exposure levels.

(2) Aiming the laser with the eye should be avoided to prevent looking along the axis of the beam, which increases the hazard from reflections.

(3) Work with lasers should be done in areas of high general illumination to keep pupils constricted and thus limit the energy which might inadvertently enter the eyes.

(4) Safety eyewear designed to filter out the specific frequencies, characteristic of the system,affords partial protection. Safety glasses should be evaluated periodically to ensure maintenance of adequate optical density at the desired laser wavelength. There should be assurance that laser goggles, designed for protection from specific lasers, are not mistakenly used with different wavelength lasers. Laser safety glasses exposed to very intense energy or power density levels may lose effectiveness and should be discarded.

(5) The laser beam should be terminated by a material that is nonreflective and fire resistant, and an area should be cleared of personnel for a reasonable distance on all sides of the anticipated path of the laser beam.

(6) Suitable precautions to avoid electrical shock should be followed in connection with the potentially dangerous electrical circuits (both high and low voltage).

b. Special Precautions for High-Powered Pulsed Lasers

(1) Safety interlocks at the entrance to the laser facility should be constructed so that unauthorized or transient personnel are denied access to the facility while the laser power supply is charged and capable of firing.

(2) Laser electronic firing systems should be designed so that accidental pulsing of a stored charge is avoided. The design should incorporate a "fail-safe" system.

(3) An alarm system including a muted sound, flashing lights (visible thru laser safety eyewear) and a countdown is advisable once the capacitor banks begin to charge.

(4) Installations using liquid nitrogen coolant should be adequately ventilated.

(5) Walls and ceiling should be painted with diffuse non-gloss paint, preferably black, near the target area, and a light color elsewhere, to increase ambient light level.

(6) Where feasible, solid-state lasers such as ruby pulsed devices, because of their higher power output (in the megawatt and gigawatt range), should be operated by remote control firing with television monitoring to eliminate the requirement for personnel to be in the same room with the laser. An alternative is to enclose the laser and beam within a light-tight box.

c. Special Precautions for Low Powered Gas C. W. and Semi-Conductor Lasers*

It is especially important to avoid the hazard from specular reflection, during the alignment of the beam by eye.

(1) The use of a diffuse matte to position the beam is advisable, but the matte should be of such a color, or reflectivity, as to minimize reflection while still making the beam visible.
(2) Elimination of all reflective material from the area of the beam (good housekeeping) is essential.
(3) Higher power (watt range) infrared lasers such as the CO_2 laser (10 microns) must be used with the utmost precaution, due to its invisible beam and the associated fire hazard.

d. Carbon Dioxide - Nitrogen (CO_2-N_2) Gas Lasers

(1) The principal hazard associated with the CO_2-N_2 lasers is the fire hazard. A sufficient thickness of firebrick or asbestos should be provided as a backstop for the beam.
(2) The laser assembly should be constructed of a material opaque to ultraviolet light generated by the gas discharge. Quartz tubing transmits ultraviolet light, whereas certain heat-resistant glass tubing is reasonably opaque at this part of the spectrum.
(3) Reflections of the infrared laser beam should be attenuated by enclosure of the beam and target area, or by eyewear constructed of a material opaque to the CO_2 wavelength, such as plexiglass.

e. Additional Precautions for Lasers in an Outdoor Environment

(1) Personnel should be excluded from the beam path to a distance where power or energy density is within permissible levels. This may be accomplished by: The use of physical barriers; administrative control; interlocks; and limiting beam traverse.
(2) The inadvertent or intentional tracking of non-target vehicular traffic or aircraft should be prohibited if it is within the calculated hazardous distance.
(3) Operation of the laser in rain, snow, fog or dust should be avoided.
(4) The beam path should be cleared of all objects capable of producing potentially hazardous reflections.

* High powered Gas and Semi-Conductor Lasers are to be treated as Pulsed Lasers.

f. Warning Signs

Evaluation of each anticipated operating condition should include the consideration and development of procedures for ensuring the proper placement of warning signs for that operation. Local standard operating procedures should prescribe the placement of temporary or permanent signs during periods of operation. A sign such as that shown below should be used.

8. PERSONNEL PROTECTIVE EQUIPMENT

a. Selecting Appropriate Eyewear

1) Determine wavelengths of laser output.

2) Determine required optical density-Table B-IV lists required optical densities for various laser beam intensities which could be incident upon safety eyewear. To determine the maximum incident beam intensity consider the following:

a) If the emergent beam is not focused down to a smaller spot, and if the beam is greater in diameter (or area) than the pupil (approximately .7 cm diameter and .4 cm^2 area), the emergent beam energy/power density may be considered the maximum intensity that could reach the eye, and is, thus, used in Table IV (see Example 1).

b) If the emergent beam is focused after emerging from the laser system, it is difficult to determine the maximum energy/power density which could enter the eye. In this case and for beams whose diameters or areas are less than pupil size, divide the laser output energy/power by the area of the pupil (approximately 0.4 cm^2). This energy/power density may be used in Table B-IV. NOTE: Many He-Ne lasers possess beams much smaller than the eye pupil (see Example 2).

c) If the observer is in a fixed position and cannot receive the maximum output energy or power density because of beam divergence, then a measured value may be used; e.g., downrange from laser beam.

d) Eyewear utilized with any pulsed laser having an energy density of 10 J/cm^2 or greater must be periodically examined for small holes and other signs of degradation. This can be accomplished by holding eyewear against a strong background light and examining with the naked eye or by using a magnifying glass.

NOTE: Table B-V presents optical densities of laser protective eyewear available from commercial sources. The optical densities are given for the principle laser wavelengths.

b. Exposure of the skin of personnel should be prevented by the use of protective gloves where only the hands are to be involved. Where other than the hands are to be exposed, protective coverings, or shields, should be used. The face should be turned away from the target area. Laser welding facilities should have sufficient shielding surrounding the article being welded.

c. Imprevious, quick-removal type, gloves, face shields, and safety glasses should be provided as minimum protection for personnel who handle the extremely low temperature liquid coolants used in higher powered lasers.

9. REQUESTS FOR TECHNICAL ASSISTANCE

Assistance in evaluating potential health hazards to Army personnel from the operation or testing of laser equipment is available from the U. S. Army Environmental Hygiene Agency, Edgewood Arsenal, Maryland 21010. This agency maintains a capability for investigating and evaluating health hazards associated with the use of this equipment. The services of the Agency are available upon

TABLE B-IV

ATTENUATION OF LASER SAFETY GLASS

O.D.	db Attenuation	Attenuation Factor	Q-switch Max. Energy Density (j/cm^2)	Non-q-switch Max. Energy Density (j/cm^2)	C. W. Max Power Density (watts/cm^2)
0	0	0	10^{-8}	10^{-7}	10^{-6}
1	10	10	10^{-7}	10^{-6}	10^{-5}
2	20	10^{+2}	10^{-6}	10^{-5}	10^{-4}
3	30	10^{+3}	10^{-5}	10^{-4}	10^{-3}
4	40	10^{+4}	10^{-4}	10^{-3}	10^{-2}
5	50	10^{+5}	10^{-3}	10^{-2}	10^{-1}
6	60	10^{+6}	10^{-2}	10^{-1}	1.0
7	70	10^{+7}	10^{-1}	1.0	10
8	80	10^{+8}	1.0	10	100

Examples of Utilizing Tables B-IV and B-V:

1. Given: A ruby Q switch laser with beam diameter of .8 cm, an energy level of .2 J or .1 J/cm^2 at 6943 Å.
   Solution: From Table B-IV an OD of 7 is required, from Table B-V five companies supply eyewear which satisfy this requirement. Good choices might be American Optical No. 585 or Bausch and Lomb No. 57. It should be noted that American Optical No. 585 has a 35% visible light transmission as compared to ~ 3% for Bausch and Lomb No. 57 which indicates that operators wearing the 585 type would see better than those wearing the 57 type.

2. Given: A He-Ne laser, beam diameter of 0.05 cm, emits 40 mW at 6328 Å, and only 4 mW at 11,300 Å.
   Solution: Since beam diameter is less than pupil diameter, it is necessary to divide these laser output powers by the area of the pupil. This yields 100 mW/cm^2 and 10 mw/cm^2. From C.W. column, Table B-VI, 100 mW requires an OD of 5 and 10mW/cm^2 requires an OD of 4. From Table B-V, the only eyewear which provides an OD of 5 at 6328Å and an OD of 4 at 11,300Å is Spectralab Eyewear.

$$*OD = \log_{10} \frac{\text{Intensity Incident Beam}}{\text{Intensity Transmitted Beam}}$$

TABLE B-V

OPTICAL DENSITIES AT VARIOUS WAVELENGTHS

MANUFACTURER:		American Optical						Bausch & Lomb 5W37 Series					TRG	Spectralab
MODEL:		580 586 569p	570	584	585	598	599	54	55	56	57	58	112	
Wavelength	**Source**													
3471	Ruby (2nd Harmonic)							30					2	
4500		<1	<1	<1	<1	17	14	17	7	1	1	1	<1	
4579	Argon	<1	<1	<1	<1	16	13	16	7	<1	<1	1	<1	
4880	Argon	<1	<1	<1	<1	13	11	14	3	<1	<1	1	<1	5
5145	Argon	<1	<1	<1	<1	9	8	12	<1	<1	<1	1	<1	5
5300	Neodymium (2nd Harmonic)	<1	<1	<1	<1	7	6	10	<1	<1	1	1	<1	
6118	He-Ne	1	3	<1	1	<1	<1	1	<1	10	3	1	2	4
6328	He-Ne	2	4	1	3	<1	<1	<1	<1	13	4	1	3	5
6471	Krypton	2	4	1	3	<1	<1	<1	<1	14	5	1	3	
6943	Ruby	3	6	5	8	<1	<1	<1	<1	15	7	2	10	9
8400	Ga-As	4	5	13	21	<1	<1		<1	5	11	4	27	18
9050	Ga-As	3	4	13	22				<1	3	11	5	28	
10600	Neodymium	2	2	11	17							8	21	13
10840	He-Ne	2	2	10	16							8	20	9
11500	He-Ne	1	1	8	13							8		9
33900	He-Ne													
% VISIBLE LIGHT TRANSMISSION:			10	46	35	23.7	24.7	4.3	57.0	6.16	~3	3.0		

NOTE: Another characteristic of these goggles which should be considered in the selection of laser protective eyewear is the maximum irradiance before damage of filter plate.

SOURCE: American Optical Company, Safety Products Division, Southbridge, Massachusetts, 01550
Bausch & Lomb, Rochester, New York 14602
TRG Inc., Route 110, Melville, New York 11749
Spectralab, 12484 Gladstone Avenue, Sylmar, California 92400

request to: The Surgeon General, ATTN: MEDPS-P, Department of the Army, Washington, D. C. 20315.

10. CALCULATIONS

a. The following symbols are used in laser computations:

E = level of radiation leaving the laser (output measured in milliwatts or watts; pulsed output measured in joules)
r = range from the laser to the point of concern (cm).
r_1 = range from the laser target to the point of concern (cm).
I = intensity at range, r, measured in joules/cm^2 for pulsed, and watts/cm^2 for C. W. lasers.
I_0 = emergent Beam intensity at zero range.
a = diameter of emergent laser beam (cm).
ϕ = emergent beam divergence measured in radians
e = base of natural logarithms
μ = atmospheric attenuation coefficient (cm^{-1}) at a particular wavelength.
f = effective focal length of eye in air (1.7 cm)
θ_{min} = minimun angle subtended by the minimal retinal spot size (radians)
d_e = diameter of the pupil of the eye (varies from approximately 0.2 to 0.8 cm)
D_e = diameter of the exit pupil of an optical system (cm)
D_L = diameter of laser beam at range r (cm)
D_o = diameter of objective of an optical system (cm)
d_{min} = diameter of minimal spot on retina (cm)
R = spectral reflectance of a diffuse object
P = magnification or power of an optical system
L = ratio of retinal energy or power density for an optically aided eye to retinal energy or power density for an unaided eye

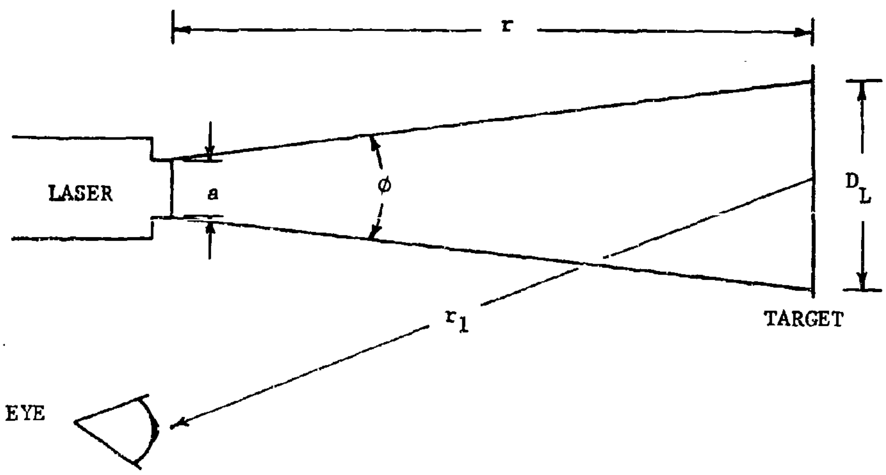


Figure B-4. Graphical Representation of the Symbols Used

b. The following formulas are used:

(1) Beam intensity for non-diverging beam at range, r, which is attenuated by the atmosphere is:

$$I = I_0 e^{-\mu r} \tag{1}$$

NOTE: The attenuation coefficient, μ, varies from 10^{-4} per cm in thick fog to 10^{-7} in air of very good visibility. The Rayleigh scattering coefficient at 6943Å is 4.8×10^{-8} cm^{-1}, and 1.8×10^{-8} cm^{-1} at 5000Å. The effect of aerosols in even the cleanest atmospheres usually raises μ at 6943Å to at least 10^{-7} cm^{-1}.

(2) Beam intensity at range, r, (direct circular beam) is the total energy in the beam at that range divided by the area of the beam at that range:

$$I = \frac{E\, e^{-\mu r}}{\pi \left(\frac{a + r\phi}{2}\right)^2} \tag{2}$$

NOTE: Accurate only for small ϕ; i.e., accuracy of ϕ better than one percent for angles below .17 radian (10°) and better than five percent for angles less than .37 radian (21°).

Example 1: To find the energy density at 1 Km (10^5 cm) of a 0.1 joule ruby laser which has a beam divergence of 1 milliradian (10^{-3} radians) and an emergent beam diameter of 0.7 cm:

$$I = \frac{(0.1\ j)\quad e^{-(.01)}}{3.14\left[\frac{0.7 + (10^5)(10^{-3})}{2}\right]^2} = \frac{(0.1)\ (.99)}{3.14\left(\frac{0.7 + 100}{2}\right)^2}$$

$$= 1.25 \times 10^{-5}\ j/cm^2.$$

(3) Minimum beam diameter at range r:

$$D_L = a + \phi r, \text{ for small } \phi \tag{3}$$

Example 2: To find the diameter of a laser beam at one kilometer where the emergent beam diameter is 10 cm and the beam divergence is 0.1 milliradian:

$$D_L = 10^5\,\text{cm} + (10\ \text{cm})(10^{-4}\text{milliradians}) = 10 + 10$$

$$= 20\ \text{cm}$$

(4) Reflected energy density from diffuse reflector:

$$I = \frac{ER}{\pi r_1^2} \quad (\text{for } r_1 \gg D_L) \tag{4}$$

Example 3: To find the maximum reflected energy density from a diffuse matte of reflectance 0.6 which would return a distance of 10 meters to the operator of a 0.1 joule laser:

$$I = \frac{(0.1j)(0.6)}{(3.14)(10^3 cm)^2} = 1.91 \times 10^{-8} \ j/cm$$

(5) Limiting angle for extended object:

$$\theta \min = d_{min} \ f$$

$$= 0.5 \text{ milliradians for } d_{min} = 10 \text{ microns} \quad (5)$$

(6) Ratio L or power density at the retina when viewing is aided by an optical system, as opposed to viewing by the naked eye:

(a) Direct viewing and specular reflection (or diffuse spot unresolved by eye and optical system):

$$L = \frac{D_O^2}{d_e^2} \quad \text{for } d_e \geqq D_e \quad (6)$$

and $$L = \frac{D_O^2}{D_e^2} = P^2 \text{ for } d_e \leqq D_e \quad (7)$$

(b) Indirect viewing of a diffuse reflection; extended objects only (i.e., object subtends angle greater than .5 milliradians when magnified):

$$L = \frac{D_O^2}{P^2 d_e^2} \quad \text{for } d_e \geqq D_e \quad (8)$$

and $$L = \frac{D_O^2}{P^2 D_e^2} = 1 \text{ for } d_e \leqq D_e \quad (9)$$

Example 4: The laser operator of Example 3 desires to view the laser flash thru a pair of 10x50 binoculars (i.e., $P = 10$ and $D_O = 50$ mm). For bright daylight find the relative hazard to this man's eyes. Since the exit pupil is not given, Equation 8 will give a conservative, if not exact answer:

$$L = \frac{(5cm)^2}{(10)^2(0.3 \ cm)^2} = \frac{25}{(100)(.09)} = 2.78$$

The hazard is equivalent to a corneal irradiance on the naked eye of: $(2.78)(1.91 \times 10^{-8} j/cm^2) = 5.3 \times 10^{-8} \ j/cm^2$.

Example 5: A laser operator views a specularly reflected beam at a point where the beam energy density measures $2 \times 10^{-9} \ j/cm^2$. If he were to

view the beam through a pair of 7 X 50 binoculars, what would be the relative hazard compared with unaided viewing? The magnification, P, of the binoculars is 7 and, if inserted in equation 7 will provide the simplest solution:

$$L = P^2 = 7^2 = 49$$

Thus, the operator would be viewing a level 49 times greater than by the naked eye, or a corneal irradiance of nearly 10^{-7} j/cm^2.

11. ADDITIONAL PERTINENT INFORMATION

The foregoing problems should not be interpreted as indicating that in the field, a fine line can be drawn where hazardous levels end and safe levels begin. Because of the great ranges involved, a backstop such as a mountain should be utilized, when possible, to terminate laser beams.

If an object is shiny to the extent that you could shave yourself by looking at such object, then a specular reflection will result when beam impinges on this object. Other duller surfaces will result in diffuse reflections radiating in all directions. (See Figure B-5)

Buffer zones (see Examples on pages B-18 and B-19 should be placed at the limits of the target area. The extent of the buffer zone is greatly dependent on the aiming accuracy and stability of the mount of the particular laser in use and the area being fired on.

A Laser Range Safety Officer should be appointed for each laser operation. He should be fully aware of hazards due to specular reflections, and the increased hazard resulting from the use of optical viewing instruments within the beam, or in observing specular reflections.

If personnel are downrange during laser operation, adequate protective eyewear should be utilized by such personnel. Adequate communications should be maintained at all times during such instances.

Airborne laser operations require the consideration of specular reflections from still water surfaces and ability to control the beam path. It is recommended that USAEHA evaluate the potential hazards of airborne laser equipment prior to use.

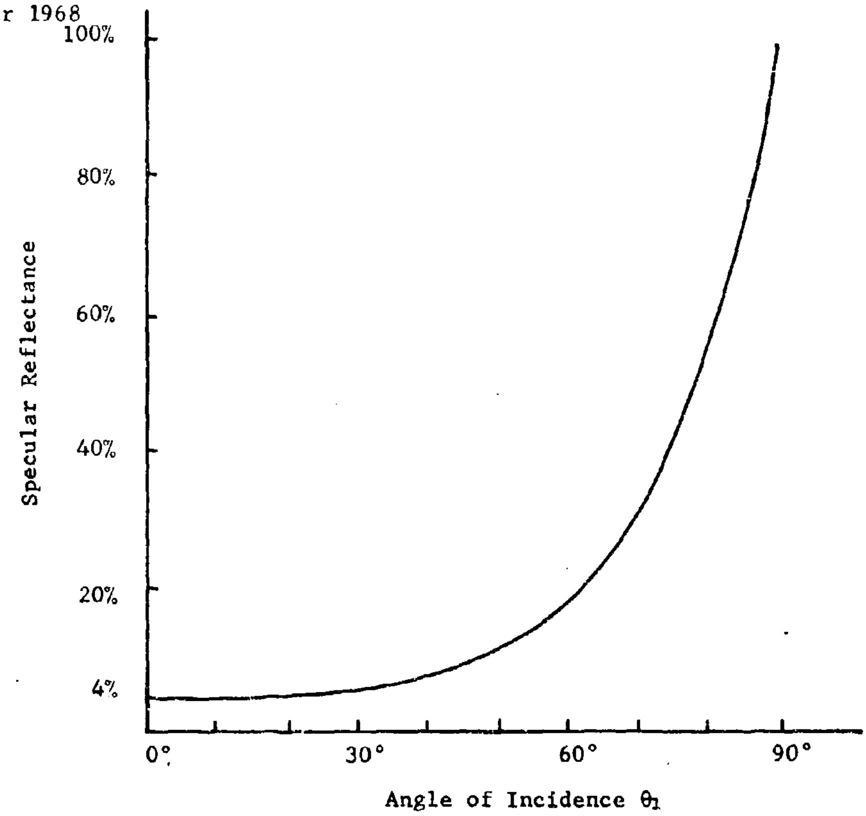
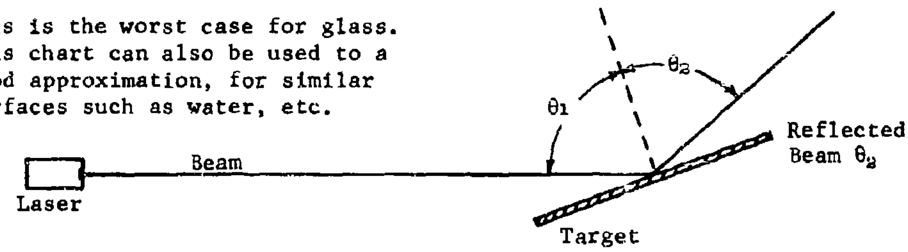


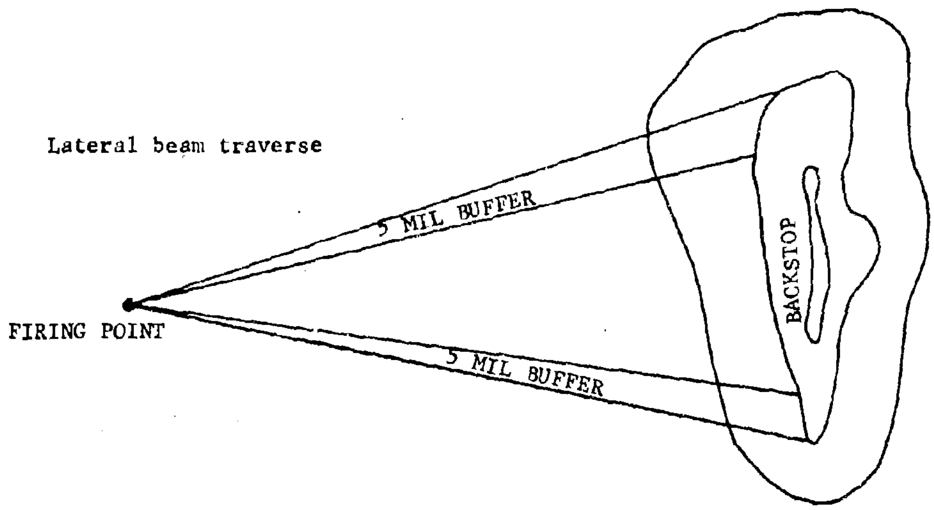
Figure B-5. Specular Reflectance From * Glass

*NOTE: This is the worst case for glass. This chart can also be used to a good approximation, for similar surfaces such as water, etc.

Example:



Explanation: The above chart indicates that as the angle θ becomes larger, most of the beam energy will glance off target surface and continue on with a slight change in direction.



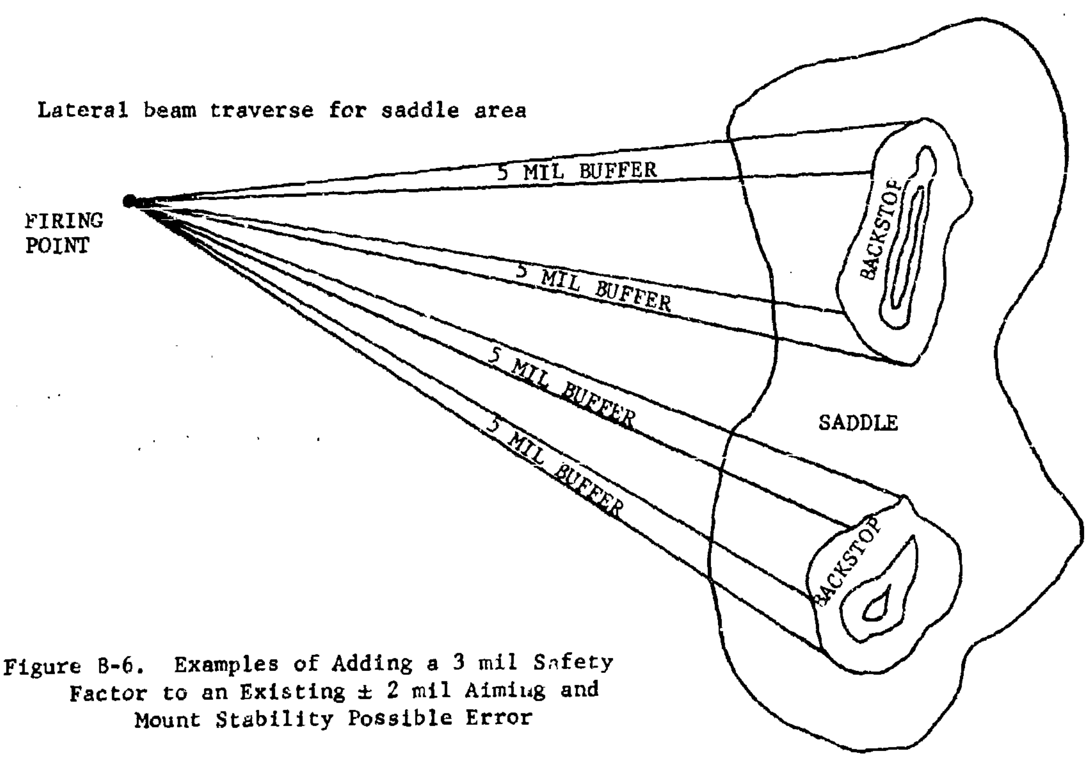
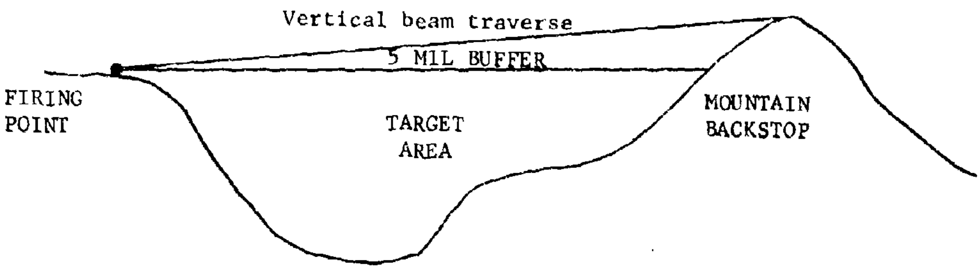
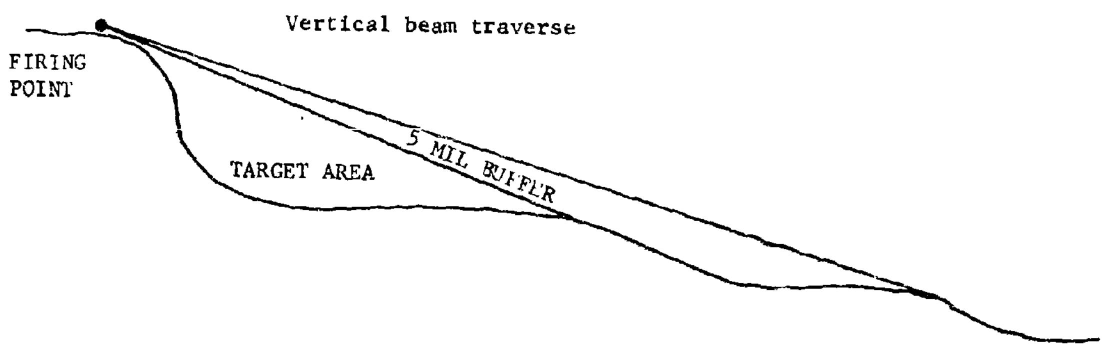


Figure B-6. Examples of Adding a 3 mil Safety Factor to an Existing ± 2 mil Aiming and Mount Stability Possible Error



Profile "A" Mountain as Backstop



Profile "B" Flat Ground as Backstop

Figure B-7. Examples of adding a 3 mil Safety Factor to an Existing ± 2 mil Aiming and Mount Stability Error